Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 150 (2016) 1748 – 1753
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Numerical Analysis of Spatial Structural Node Bearing Capacity in the View of the Geometrical and Physical Nonlinearity

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Abstract

The authors set the task to calculate and design the connection node of spatial rod constructions; the calculations were carried out in view of the geometrical and physical nonlinearity. To that effect, the solid-state node model was created and a numerical simulation was carried out. Based on calculation results, the authors obtained values of node deformations and equivalent stress, and completed their analysis. It was found that the node clamp disk, one of the node elements, undergoes a plastic deformation when subject to loadings. The node stiffness was enhanced by entering additional elements. Parameters of the enhanced node in the stress-strain state were re-calculated in a nonlinear formulation. The upgraded node construction can be recommended for the efficient industrial use.
The proposed design technique allows the authors to evaluate structural behavior at all stages of the life cycle: model creation, preparation of design documentation, manufacture, operation in all modes and conditions.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: Spatial rod constructions of coating; node of spatial rod constructions; numerical simulation; geometrical and physical nonlinearity; solid-state node model; numerical experiment.

1. Spatial rod constructions of coating

Efficient building constructions with a body of high performance properties are being developed in recent years to create complex forms of spatial surfaces in buildings and structures [1-4]. Spatial metal structures that meet the requirements of functionality, aesthetics and design ability are the most promising in this respect.

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Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.165

Spatial rod constructions of coating (SRC) are particularly popular worldwide. They enable a rational manner to search for various options of space planning solutions, create buildings of multipurpose functional use due to application of large-span transformable structures, diversify architectural forms and compositional tools [5-8].

At the basis of contemporary global trends in construction industry development lies the increasing degree of prefabrication of building structures and their components, reduction of materials consumption and manufacturing labor hours [9].

The spatial rod constructions of coating meet these requirements to the uttermost as they allow to reduce the costs of their large output, production specialization and rationality of design solutions [10].

The technology of the mass production of the SRC is optimum, if the greatest possible number of similar parts made without changeover equipment. All parts of the structure should be unified, have a minimum number of standard sizes. The all parts of the construction must be easy for transporting. The complexity of the nodal connections and requirement of high accuracy during manufacture and assembly hamper the introduction of such constructs into mass production [11].

2. Solid-state node model and numerical simulation

The computer simulations of the SRC, the use of CAD software complexes for automation of activities on stages of design and technological preparation of production are allow to reduce the time for completion of design development, improve the quality and reliability of the design and manufacture of elements and construction units [12].

The authors have set the task of designing automation SRC, they want to create a procedure for perform engineering design and prepare the design documentation and design drawings for fabrication elements of the system.

Model SRC (see Figure 1) has been created through the computer system Structure CAD [13]. Structure CAD based on the finite element method (FEM) and intended to perform strength analysis of various types and purposes of building structures.

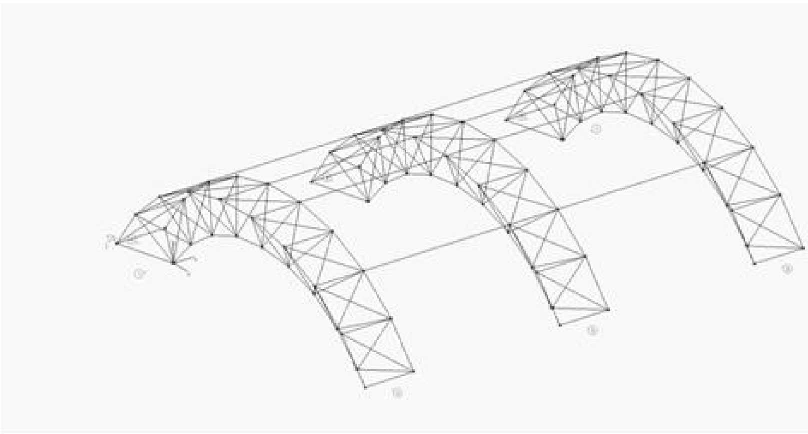

Fig. 1. Model of SRC in StructureCAD.

The investigated structure is calculated on the weight of the light roof and snow through the computer system Structure CAD. The resulting force values were used to calculate the unit [14].

The unit was cut out from the model SRC and its solid model was created in the program SolidWorks [15]. The solid model of the unit (Figure 2) was transferred to ANSYS [16] for the numerical analysis of the its bearing ability, taking into account the physical and geometric nonlinearity.

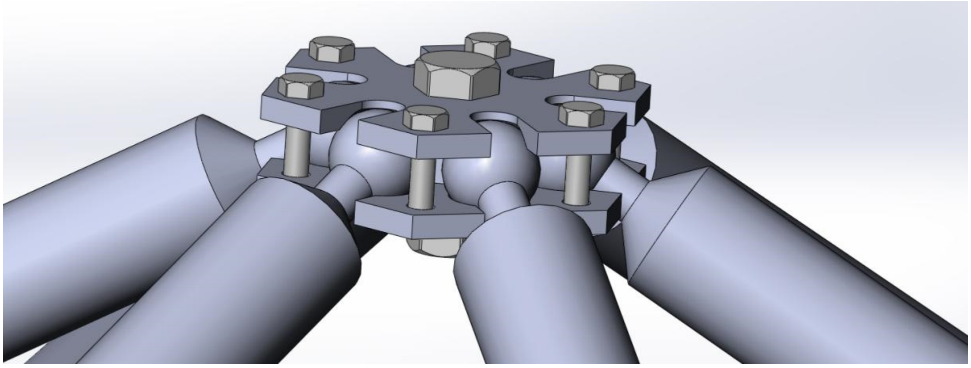

Fig. 2. Solid model of the unit, created in the program SolidWorks.

Limit unit status occurs or when a plastic deformation or the destruction. When unit is in uniaxial stress state, design limitation may be yield strength or Ultimate tensile strength.

The triaxial state of stress with σ_1, σ_2, σ_3 is characteristic for this task. This complicates the solution. The value of the principal stresses, at which the transition occurs from the elastic state to limit state, must be obtained.

Defects in the plastic material (in the steel) will begin to appear in places where the value of equivalent stress von Mises σ_{eq} exceeds the limit stress [17]. The Ultimate stress σ_{lim} is the yield strength σy in the most cases.

$$\sigma_{eq} = f(\sigma_1 \cdot \sigma_2 \cdot \sigma_2) = \sigma_{lim} \tag{1}$$

The load-carrying ability of node was estimated by deformations and values of equivalent stress Mises. The authors obtained calculated values of node deformations and equivalent stress in ANSYS [18] (Figure 3 and 4).

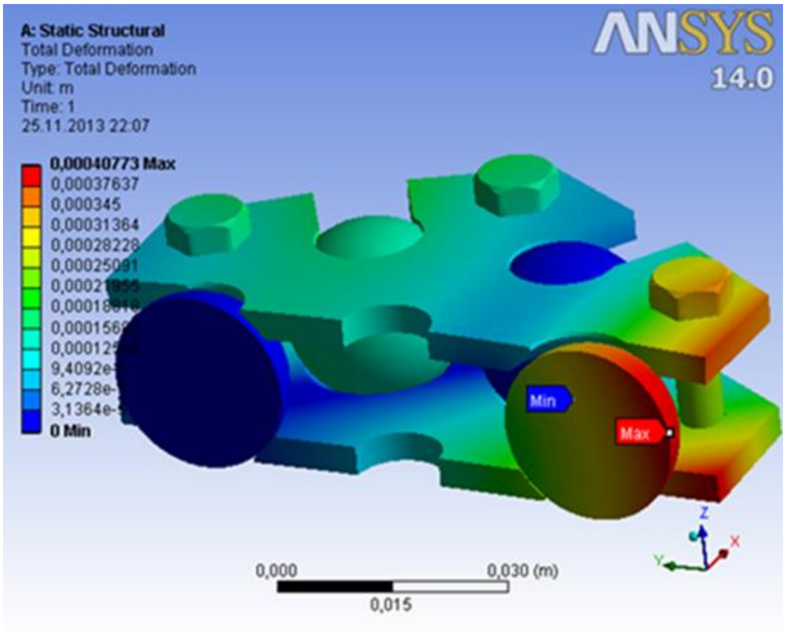

Fig. 3. The distribution of deformation in the node

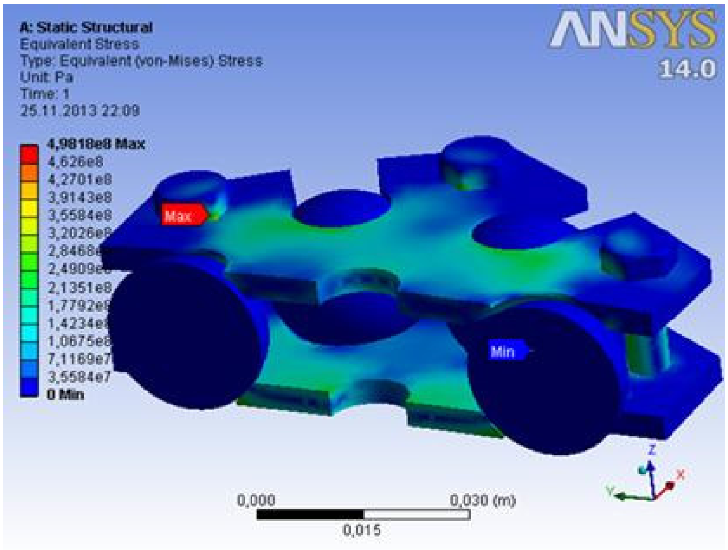

Fig. 4. The distribution of equivalent stress von Mises in the node

Based on calculation results [19] the authors completed their analysis. It was found that the node clamp disk, one of the node elements, gets plastic deformation when subjected to loadings. The node stiffness was enhanced by entering additional elements (Figure 5).

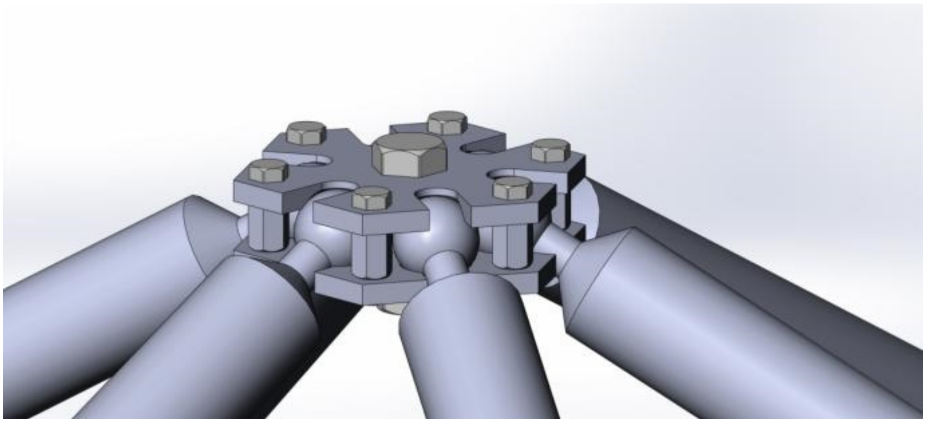

Fig. 5. Solid model of the unit with additional elements

The calculation model with the division into finite elements is shown in Figure 6. Parameters of enhanced node in stress-strain state were re-calculated [20] in nonlinear formulation [21].

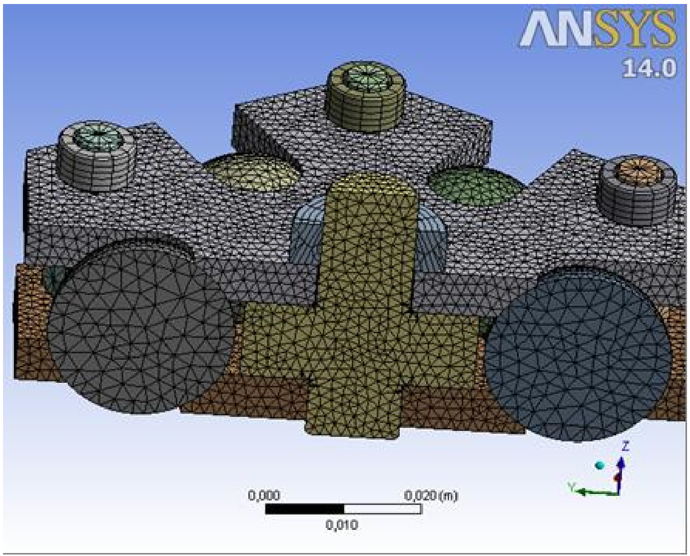

Fig. 6. The calculation model with the division into finite elements

The distributions of deformation and equivalent stress von Mises in the node with entering additional elements are shown in Figure 7 and 8.

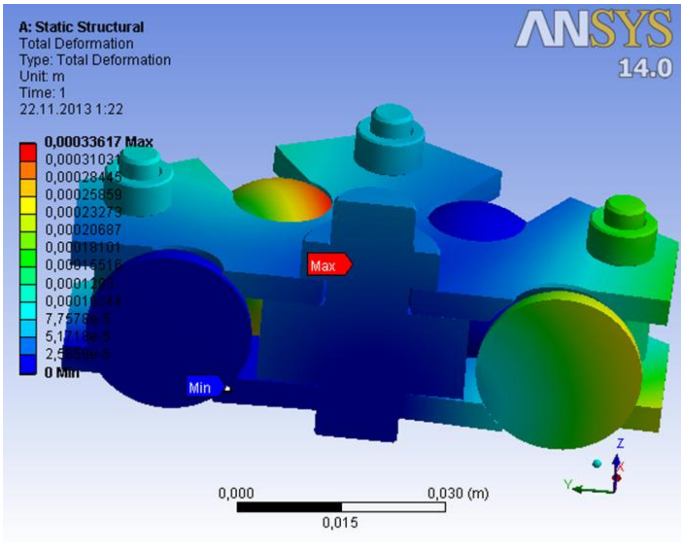

Fig. 7. The distribution of deformation in the enhanced node

The upgraded node construction can be recommended for efficient industrial use. The proposed design technique allows the authors to evaluate structural behavior at all stages of the life cycle: model creation, preparation of design documentation, manufacture, operation in all modes and conditions.

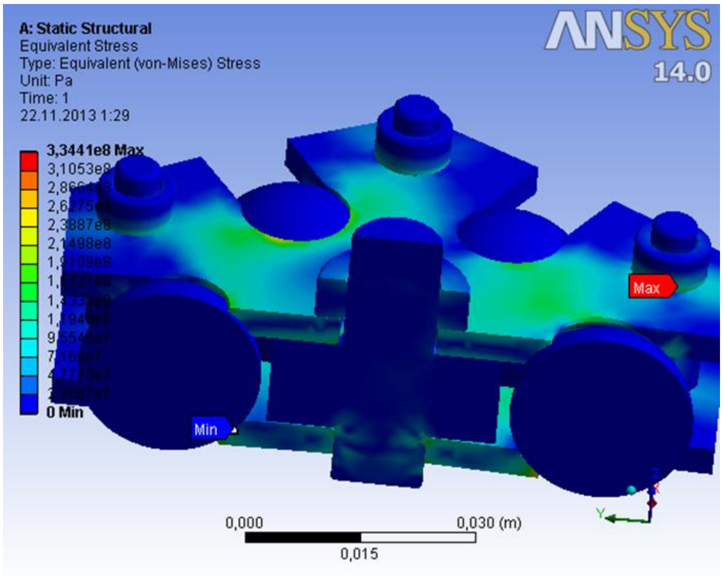

Fig. 8. The distribution of equivalent stress von Mises in the enhanced node

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